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NWSY TR 77-1

A SAFETY, QUALITY AND COST EFFECTIVENESS STUDY OF COMPOSITION A-3 PRESS LOADING PARAMETERS (II)

MARCH 1977

NWS

NAVAL WEAPONS STATION, YORKTOWN, VIRGINIA 23691

by
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This report presents further details of a safety, quality and cost effectiveness study of loading gun ammunition with Composition A-3 explosive previously reported in NWSY TR 76-1.

Processing parameters were required to increase gun firing safety and increase explosive load quality using material with a bulk density of less than 0.81 g/cc at the lowest possible cost.

The temperature and pressing efforts were investigated and production processing parameters were established.

The problem of explosive cracking after temperature cycling was traced to the new type waxes being used in the manufacture of the Composition A-3. The ram configuration, pressing pressure, increment weights and sizes were optimized for a limited range of temperatures.

F O R E W O R D

1. This report presents further details of NWSY TR 76-1, *A Safety, Quality and Cost Effectiveness Study of Composition A-3 Press Loading Parameters,* and deals with temperature and pressing effect studies only. Technical approach and data reduction procedures are not repeated except for those portions that lend continuity and make for reader convenience.

2. The effort reported herein was authorized and funded under the Naval Sea Systems Command (SEA-9923E) Work Request 53555 of 21 Aug 1974 and Work Request 53557 of 7 Aug 1974.

Released by

W. McBride

W. McBRIDE, Director
Naval Explosives Development
Engineering Department
March 1977

Under authority of
LEO A. HIBSON, JR.
Commanding Officer

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The name of John M. Thomas, NAVWPNSTA Yorktown, who ferreted out and helped reduce improbable volumes of data to manageable proportions, must be added to those already identified in the first of these reports, NWSY TR 76-1.

CONTENTS

CONTENTS (cont'd)

A SAFETY, QUALITY AND COST EFFECTIVENESS STUDY OF COMPOSITION A-3 PRESS LOADING PARAMETERS (II)

I. BACKGROUND

The Naval Explosives Development Engineering Department (NEDED) of the Naval Weapons Station (NAVWPNSTA), Yorktown, Virginia was tasked to define a matrix of operation parameters that would allow the continued production of Comp A-3 loaded gun launched ammunition without compromising in any way the quality standards of the end product. During phase I of that task temperature variations and pressing parameters could not be thoroughly examined and reported due to time limitations imposed by immediate production problems. This report completes the assigned task.

For many years loading plants have reported both processing and quality problems resulting from seasonal, ambient pressing temperature variations during Comp A-3 projectile loading. These problems are related to the desensitizing wax component of the Comp A-3. At low temperatures the wax hardens and proper flow and consolidation is inhibited. At high temperatures the wax becomes tacky and sticks to the press rams. Also, in warm weather, loading plants complain of "reassertion" which is defined as post-pressing growth of the Comp A-3 in the loaded projectile. It was suspected that reassertion resulted from the gradual expansion of compressed air that had been trapped in warm, tacky Comp A-3 during the press loading operation. The reassertion problem was resolved but in a time consuming and costly way. It consisted of holding all press loaded projectiles for at least 24 hours before drilling the fuze cavity and then waiting an additional 2 hours before gauging the fuze cavity depth for final acceptance.

After 1973 another potential problem related to the Comp A-3 wax component arose. Certain process changes were made by the petrochemical industry to their raw, oil feed stocks as a direct result of the 1973 oil embargo. The result was that waxes produced subsequently, even though meeting relevant military specifications, differed from older stocks in some undefinable quality. For example, the Naval Weapons Support Center (NAVWPNSUPPCEN), Crane, Indiana reported that projectiles loaded with Comp A-3 containing these "new" waxes occasionally exhibited cracks when radiographed shortly after pressing. Normally projectile loads are crack-free at this stage of their life cycle.

It has been generally known that all Comp A-3 loaded projectiles will crack when subjected to temperature cycling. It had also been demonstrated, when the entire inventory of 5" projectiles was radiographed by direction of the Ammunition Special Study Group,[1] that the majority of Fleet stocks had developed cracks during their field life. Test firing of 90 of the most severely cracked units at proof pressures did not result in any malfunctioning incidents. Nonetheless, it seemed important to determine whether or not projectiles that had been loaded with "new" waxes and that had developed cracks early in their life cycle might crack even more severely than those previously loaded when subjected to similar temperature-aging conditions as had been undergone by the older Fleet stocks.

Also, no data base or rationale had been previously documented for the controls that had been established for ram pressures, ram configurations, ram speeds, dwell times or number of increments pressed. For that matter, there was no indication that any of these variables might be close to or far from the upper limits of acceptable processing safety margins. A coordinated series of experiments incorporating these variables with those of the blending and temperature effects studies were matrixed.

This report describes the temperature variations and pressing parameters studies; the results obtained; and conclusions and recommendations drawn.

II. TEMPERATURE EFFECT STUDIES

A. Approach

The effect of bulk density changes upon the quality of press loaded Comp A-3 5"/38 and 5"/54 projectiles has already been described.[2] In those experiments bulk density was the only variable. All other process variables were held constant, particularly temperature which was kept at 68 degrees Fahrenheit (°F). Sufficient data was collected to assure statistically that high quality projectiles could be loaded at very high confidence levels from Comp A-3 having bulk densities ranging from 0.75 to 0.83 grams per cubic centimeter (g/cc).

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[1]NAVORD Rept 10009, *Report of the Ammunition Special Study Group (U)*, 1 Aug 1970 CONFIDENTIAL

[2]McGann, E. Yancey, Rothstein, Lewis R., NWSY TR 76-1, *A Safety, Quality and Cost Effectiveness Study of Composition A-3 Press Loading Parameters*, Mar 1976

However, before these density studies were completed, uninterrupted production of 5" gun ammunition was endangered because of the limited stocks of Comp A-3 exceeding 0.81 g/cc bulk density, the requirement at that time. Consequently, temperature effect studies were run concurrently with bulk density studies and time limitations made it necessary to evaluate multiple variables in the experimental matrix to keep production on schedule.

A two-phase temperature effect study was initiated to obtain the following information:

- Over what allowable temperature range could available supplies of 0.75 to 0.83 g/cc bulk density Comp A-3 be loaded without undue production difficulties and at the same time meet required end product densities?

- Were there any other end product quality differences between projectiles loaded with Comp A-3 manufactured after 1973 (referred to herein as "new") with different Grade A waxes as compared to projectiles loaded with Comp A-3 manufactured before 1973 (referred to herein as "old"); i.e., were post-pressing and post-cycling crack patterns different in numbers, sizes or distribution?

Because of time restraints, the first phase experiments were limited to 5"/54 projectiles only, since experience had always shown that they presented the greater difficulty in achieving specified pressed densities. Also, the number of projectiles pressed and cored per sub-set (10 projectiles, 60 cores) were insufficient to be statistically analyzed to the same high confidence levels as were those in the single variate, bulk density studies. Nonetheless, the reproducibility of the data points collected, together with the rigid controls of all other parameters such as press pressure, ram speed, etc., gave strong indications that the data's validity and the conclusions drawn therefrom were not compromised.

In the second phase experiments time also was a restraining factor, and because of both the limited capacity for temperature cycling as well as the 28 days involved, less than the statistically desired number of experiments were run. Here both 5"/38 and 5"/54 projectiles were processed.

B. Temperature-Density Studies

1. Purpose

The original plan was to evaluate the pressed densities of 5"/54 projectiles using Comp A-3 conditioned to the temperature range of 40° to 100°F while also varying the Comp A-3 bulk density from 0.75 to 0.81 g/cc. The purpose was to establish usable operating parameters for the projectile loading field stations. However, preliminary work quickly demonstrated the inadvisability of pressing Comp A-3 at temperatures above 85°F because breakdown of the compressed increments occurred in every case at 100°F and, in some cases, at 90°F. (Breakdown is the sudden collapse of the explosive column under the ram allowing the ram to accelerate beyond the 85 inches per minute safety limit.)

Also, it was determined very early that press loading Comp A-3 conditioned to temperatures below 50°F gave unacceptably low density end product projectiles.

Hence, from a practical standpoint, controlled primarily by the physical properties of the wax binder, the temperature range studied was limited to 55° through 78°F. This 23°F range was considered broad enough to allow production facilities to operate within the ambient temperature fluctuations normally experienced.

The experimental matrix is listed in Table I. In all, 150 projectiles were pressed and 900 core samples analyzed. Because of time limitations, only 10 projectiles were loaded at each fixed temperature/bulk density rather than the more statistically meaningful 50. All other parameters were held constant as listed in Table I.

2. Results

Figure 1 is a graphical representation of the results. Each point represents the average of 60 core densities taken from the 10 projectiles pressed[2] at the specific temperature and bulk density indicated. It is obvious that core densities increase significantly with temperature for all bulk densities and that additionally, at the highest temperature, 78°F, the spread narrows to .006 g/cc (i.e., 1.626 to 1.632) as compared to a .010 g/cc spread (i.e., 1.609 to 1.619) at 55°F.

This data shows that even at 55°F the lowest average density, 1.609 g/cc, lies comfortably above the 1.600 g/cc specified minimum. That this is false security is brought out in Table II which is a compilation of the lowest individual core densities found in each projectile at the temperature and bulk densities indicated. Here it can be seen that only at 78°F and the higher bulk densities, 0.79 to 0.81 g/cc, was it possible to achieve a minimum density of at least 1.600 g/cc for any projectile core.

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[2]*Ibid.* (p 11)

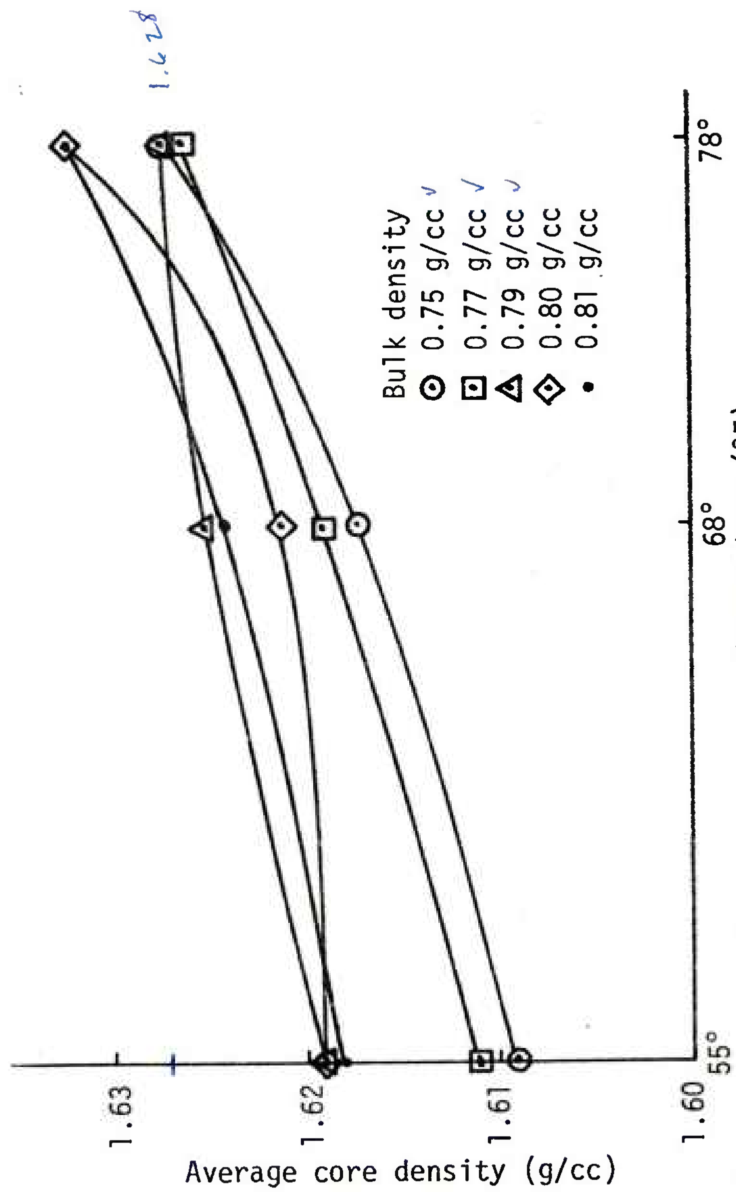
TABLE I

5"/54 PROJECTILE TEMPERATURE-DENSITY STUDY
PRESSING MATRIX

Temp	No. of projectiles loaded				
	Bulk density (g/cc)				
	0.75	0.77	0.79	0.80	0.81
78°F	10	10	10	10	10
68°F	10	10	10	10	10
55°F	10	10	10	10	10

<u>Pressing constants</u>

Comp A-3: Old (mfg before 1973)
Ram pressure: 13,250 psi
Ram speed: 85"/min
Dwell time: 6 sec
No. of incr: 6



5"/54 PROJECTILE TEMPERATURE-DENSITY STUDY
CORE DENSITY VARIATIONS

FIGURE 1

TABLE II. 5"/54 PROJECTILE TEMPERATURE-DENSITY STUDY
MINIMUM CORE DENSITY

Proj No.	Temperature 55°F Bulk density (g/cc)					Temperature 68°F Bulk density (g/cc)					Temperature 78°F Bulk density (g/cc)				
	0.75	0.77	0.79	0.80	0.81	0.75	0.77	0.79	0.80	0.81	0.75	0.77	0.79	0.80	0.81
1	1.572	1.582	1.587	1.583	1.571	1.583	1.575	1.601	1.597	1.600	1.595	1.593	1.600	1.603	1.604
2	1.569	1.578	1.586	1.590	1.592	1.582	1.574	1.593	1.605	1.600	1.595	1.603	1.595	1.602	1.602
3	1.577	1.578	1.588	1.591	1.587	1.585	1.575	1.594	1.593	1.598	1.595	1.593	1.596	1.607	1.608
4	1.573	1.568	-	1.580	1.589	1.585	1.578	1.596	1.595	1.603	1.587	1.603	1.599	1.605	1.600
5	1.574	1.572	1.584	1.583	1.560	1.581	1.577	1.601	1.584	1.605	1.588	1.586	1.597	1.603	1.607
6	1.579	1.576	1.593	1.585	1.594	1.588	1.584	1.599	1.591	1.602	1.602	1.604	1.578	1.606	1.598
7	1.571	1.575	1.589	1.581	1.577	1.555	1.586	1.600	1.588	1.599	1.584	1.594	1.605	1.612	1.603
8	1.570	1.572	1.590	1.574	1.588	1.588	1.573	1.599	1.583	1.595	-	1.585	1.601	1.607	1.607
9	1.559	1.575	1.591	1.595	1.604	1.580	1.593	1.597	1.562	1.598	1.590	1.601	1.590	1.608	1.605
10	1.564	1.558	1.598	1.584	1.599	1.577	1.586	1.573	1.593	-	1.589	1.594	1.624	1.612	1.604
Avg	1.571	1.573	1.590	1.585	1.586	1.580	1.580	1.595	1.590	1.599	1.592	1.596	1.600	1.607	1.604

3. Conclusions

It was on the basis of the above data, together with data presented in Section III, that the number of increments pressed was raised from six to eight and press pressures were increased to 15,000 pounds per square inch (psi) for 5"/54 projectiles and 14,000 psi for 5"/38 projectiles.[2] Under these conditions, it was statistically verified that there was essentially zero chance of any core lying below 1.600 g/cc if the following pressing parameters were used:

- 68° to 80°F material temperature at pressing.
- 8 increments.
- 15,000 psi (5"/54); 14,000 psi (5"/38) ram pressure.
- 6 seconds dwell time.
- 85 inches per minute ram speed.
- 0.75 g/cc minimum bulk density.

C. Temperature Cycling Studies

1. Purpose

Comp A-3 is known to crack under a variety of conditions: immediately after pressing; after fuze cavity drilling; in Fleet magazine storage; after temperature cycling.

The objectives of the experiments described in this section were:

- To determine if the numbers, locations and degrees of cracking differed between new, old and blends of new/old Comp A-3 under the conditions just described.
- To establish allowable crack criteria in production units that would be most economical without compromising safety.

From field station reports it was known already that the new Comp A-3 exhibited more cracks immediately after projectile loading than did the old Comp A-3 but not more than in Fleet stored rounds. The real question to be answered was whether or not cracks from the new material would increase in either numbers or size with time under simulated, severe Fleet storage conditions. For this reason the temperature cycling matrix listed in Table III was established for both 5"/54 and 5"/38 projectiles.

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[2] *Ibid.* (pp 15-23)

TABLE III

5"/38 AND 5"/54 PROJECTILE TEMPERATURE CYCLING STUDY
TEMPERATURE CYCLING MATRIX

Condition at X-ray	No. of projectiles cycled				
	Type of Comp A-3				
	Old	New	50/50[a]	1st incr new[b]	Fleet[c]
After loading, prior to drilling	6	6	6	6	6
After fuze cavity drilling	6	6	6	6	6
After Fleet storage	6	6	6	6	6
After temp cycling[d]	6	6	6	6	6

[a]50/50 blend of old and new.

[b]First increment new, remainder old.

[c]Randomly selected Fleet stores (old).

[d]The normal JAN cycle of 28 days from -65° to 160°F was modified to an upper limit of 135°F to preclude any cracks annealing by virtue of wax melting and resolidifying.

Cracks were identified by three categories:

- Location. - Four arbitrary crack locations were used - the fuze cavity area (defined as within 1 inch of the fuze cavity), the top, middle and bottom thirds of the projectile as marked off in Figures 2 and 3.

- Size. - Identification was by hairline, 1/64-, 1/32- and 1/16-inch gaps. All cracks were essentially horizontal and did not require orientation identification.

- Growth after temperature cycling. - Gap increases in old cracks, if any, as well as identification of newly formed cracks were so documented.

All projectiles were press loaded at the Naval Weapons Support Center (NAVWPNSUPPCEN), Crane, Indiana using standard production procedures under the conditions described in Section II.B.3. This was to eliminate any possible quality differences that might have biased the results if the rounds had been press loaded in the developmental facility at NEDED under strict engineering supervision.

All fuze cavity drilling and radiographic work was carried out at NEDED using the same procedures and technicians throughout to assure uniformity of techniques and interpretations of results.

2. Results

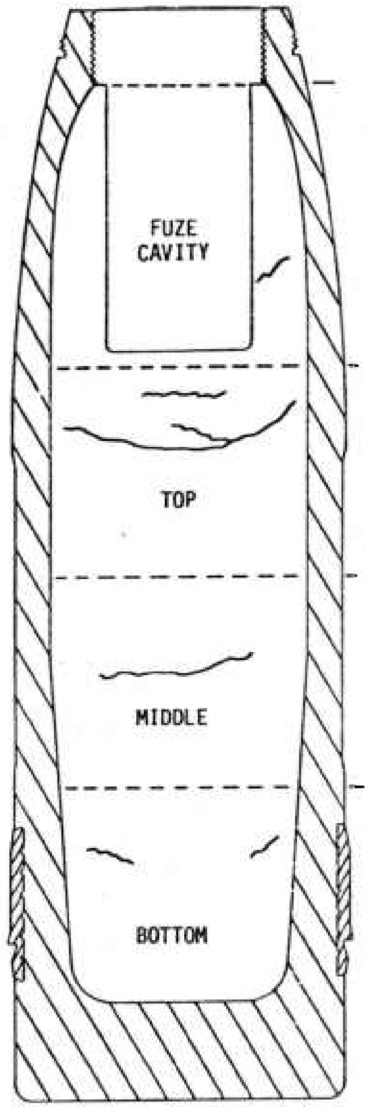
a. 5"/38 projectiles

Figure 2 summarizes the data. Each number in each square of Figure 2 represents the total number of cracks found in six projectiles. Thus, in the before temperature cycling column, (B), for old Comp A-3, the three cracks listed in the "top" portion of the projectile represent the total number found in all six projectiles for that set after both initial pressing and fuze cavity drilling.

The cracks shown on the schematic represent a composite of the distribution and lengths of the cracks found after temperature cycling. No one projectile had any more cracks than are shown on the composite.

General observations are:

- Before temperature cycling. - No cracks developed in 30 rounds after pressing but prior to drilling. Moderate cracking occurs after fuze cavity drilling but before temperature cycling, i.e., only 13 cracks were found in the sample of 30 projectiles, 12 of them hairline, the other crack was 1/64 inch. No significant difference in the



	H		1/64"		1/32"		1/16"	
	B	A	B	A	B	A	B	A
FLEET	1	3	0	0	0	0	0	0
NEW	1	4	0	1	0	1	0	0
OLO	0	0	0	0	0	0	0	0
50/50	1	1	0	0	0	0	0	0
1ST INCR	0	0	0	1	0	0	0	0

	B	A	B	A	B	A	B	A
FLEET	0	2	0	3	0	2	0	0
NEW	0	2	0	3	0	0	0	0
OLO	3	2	0	1	0	0	0	0
50/50	3	1	1	3	0	0	0	0
1ST INCR	2	3	0	1	0	0	0	0

	B	A	B	A	B	A	B	A
FLEET	0	3	0	3	0	0	0	0
NEW	0	4	0	3	0	1	0	0
OLO	0	6	0	1	0	0	0	0
50/50	0	4	0	0	0	0	0	0
1ST INCR	1	4	0	1	0	0	0	0

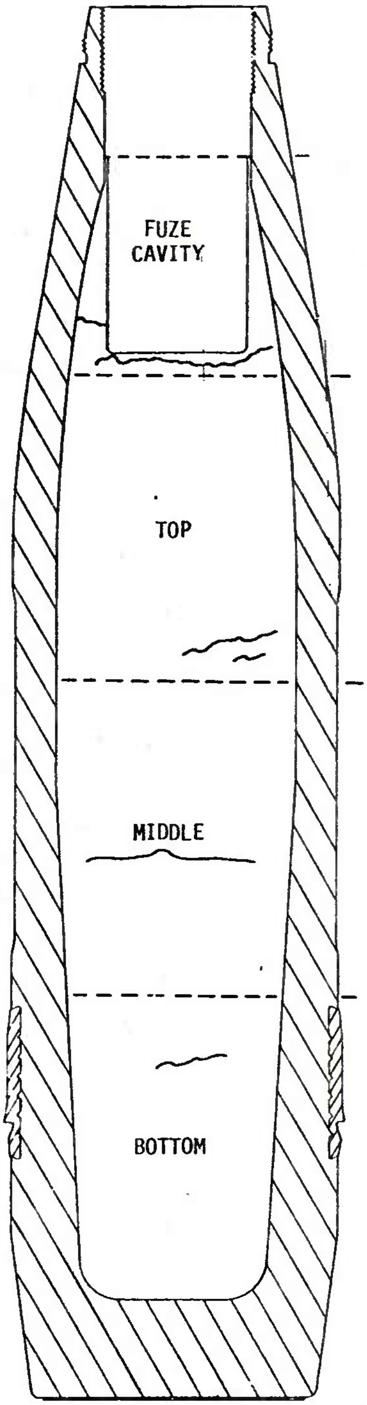
	B	A	B	A	B	A	B	A
FLEET	0	0	0	0	0	0	0	0
NEW	0	2	0	0	0	0	0	0
OLO	0	0	0	0	0	0	0	0
50/50	0	1	0	1	0	0	0	0
1ST INCR	0	0	0	0	0	0	0	0

H = HAIRLINE
B = BEFORE CYCLING
A = AFTER CYCLING

	SUMMARY									
	H		1/64"		1/32"		1/16"		TOT	
	B	A	B	A	B	A	B	A	B	A
FLEET	1	8	0	6	0	2	0	0	1	16
NEW	1	12	0	7	0	2	0	0	1	21
OLO	3	8	0	2	0	0	0	0	3	10
50/50	4	7	1	4	0	0	0	0	5	11
1ST INCR	3	7	0	3	0	0	0	0	3	10
								TOTAL:	13	68

5"/38 PROJECTILE TEMPERATURE CYCLING STUOY
CRACK SIZE AND POSITION DISTRIBUTION

FIGURE 2



FUZE CAVITY

	H		1/64"		1/32"		1/16"	
	B	A	B	A	B	A	B	A
FLEET	0	0	0	1	0	0	0	0
NEW	1	4	1	3	1	1	2	1
OLD	2	1	0	1	0	0	0	0
50/50	1	6	0	1	0	0	0	0
1ST INCR	0	5	0	0	0	0	0	0

TOP

	B	A	B	A	B	A	B	A
FLEET	1	2	0	1	0	1	0	0
NEW	0	4	0	4	0	0	0	0
OLD	3	5	0	3	0	0	0	0
50/50	0	5	0	0	0	0	0	0
1ST INCR	4	5	0	3	0	0	0	0

MIDDLE

	B	A	B	A	B	A	B	A
FLEET	2	5	0	3	0	1	0	0
NEW	0	8	0	5	0	0	0	1
OLD	1	8	0	1	0	0	0	0
50/50	0	8	0	1	0	0	0	0
1ST INCR	0	8	0	1	0	0	0	0

BOTTOM

	B	A	B	A	B	A	B	A
FLEET	0	0	0	1	0	1	0	0
NEW	0	4	0	1	0	0	0	0
OLD	0	2	0	0	0	0	0	0
50/50	0	0	0	0	0	0	0	0
1ST INCR	0	5	0	0	0	0	0	0

	SUMMARY									
	H		1/64"		1/32"		1/16"		TOT	
	B	A	B	A	B	A	B	A	B	A
FLEET	3	7	0	6	0	3	0	0	3	16
NEW	1	20	1	13	1	1	2	2	5	36
OLD	6	16	0	5	0	0	0	0	6	21
50/50	1	19	0	2	0	0	0	0	1	21
1ST INCR	4	23	0	4	0	0	0	0	4	27
TOTAL:									19	121

H = HAIRLINE
B = BEFORE CYCLING
A = AFTER CYCLING

5"/54 PROJECTILE TEMPERATURE CYCLING STUDY
CRACK SIZE AND POSITION DISTRIBUTION

FIGURE 3

numbers of cracks exists among any of the types and blends of Comp A-3 used. No cracks appeared in the bottom third of any projectile.

- After temperature cycling. - Cracking increased fivefold over uncycled rounds, i.e., from 13 to 68. Old Comp A-3 and blends or incremental loadings of old and new Comp A-3 cracked roughly only one-half as much (i.e., an average of 10 cracks per 6 rounds) than did new Comp A-3 (20 cracks per 6 rounds). On the other hand, there was no significant difference between either the numbers or sizes of cracks developed in the new material (21 versus 16 total cracks and 9 versus 8 between 1/64 inch and 1/32 inch). Only three hairline and one 1/64 inch crack appeared in the bottom third of the 30 rounds cycled.

- Growth of old cracks. - Figure 4 shows that only 3 hairline cracks of the original 13 grew after temperature cycling and that these expanded only to 1/64 inch. Simultaneously, one of the hairline cracks in the new Comp A-3 annealed and disappeared.

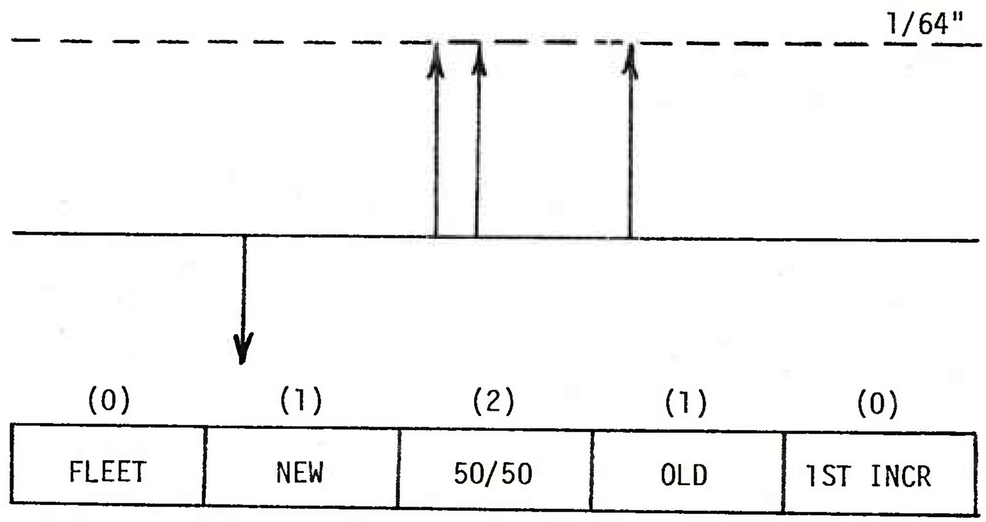
b. <u>5"/54 projectiles</u>

Figure 3 summarizes the data. Likewise, the schematic is a composite representation as described for the 5"/38 rounds.

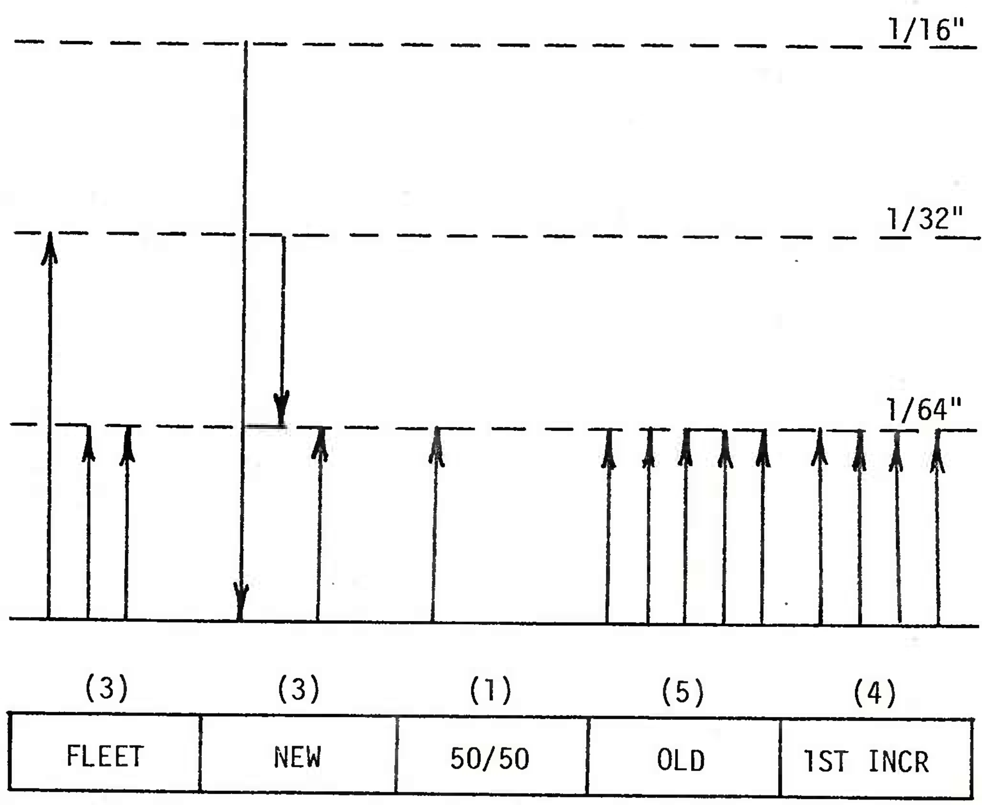
General observations are:

- Before temperature cycling. - Relatively few cracks occur before temperature cycling, i.e., 7 before and 19 after fuze cavity drilling in 30 rounds, with 15 of the cracks being hairline. However, of the other four cracks ranging from 1/64 inch to 1/32 inch, all were with the new Comp A-3. On the other hand, none exceeded 1/16 inch and all appeared in the fuze cavity area where cracks are generally conceded to be non-contributory to setback force initiation. On a total crack basis, no distinction can be found among any of the types of Comp A-3 loads with the exception that only one crack was found in the six projectiles loaded with the 50/50 blend of old and new Comp A-3. Because of the small sample size, this has no statistical significance.

- After temperature cycling. - As in the case of the 5"/38 rounds after cycling, cracking increased by roughly the same order of magnitude, i.e., sixfold. Again, new Comp A-3 showed roughly twice as many cracks, 36 per six rounds, as did any of the other Comp A-3 loads, each of which averaged about 20 per six rounds. Also, the number of cracks between 1/64 inch and 1/16 inch for new Comp A-3, 16, were roughly



5"/38 PROJECTILE



5"/54 PROJECTILE

5"/38 AND 5"/54 PROJECTILE TEMPERATURE CYCLING STUDY
CRACK GROWTH (↑) OR SHRINKAGE (↓)

FIGURE 4

four times the average of four for the other Comp A-3 loads. However, only one 1/64-inch crack developed in the bottom third of one new Comp A-3 loaded round, whereas two cracks, 1/64-inch and 1/32-inch, developed in two Fleet stores rounds.

- Growth of old cracks. - Figure 4 shows that 13 hairline cracks grew to at least 1/64 inch among all Comp A-3 loads other than new. In the latter case, two of three cracks actually annealed: one from 1/32 to 1/64 inch; one from 1/16 inch to hairline; one hairline grew to 1/64 inch.

3. <u>Conclusions</u>

The conclusions from the test results are:

- In both 5"/38 and 5"/54 projectiles, fuze cavity drilling frequently results in cracks, usually of a hairline nature and probably due to stress force release.

- Both 5"/38 and 5"/54 Comp A-3 loaded projectiles crack five to sixfold during temperature cycling.

- In 5"/38 projectiles, numbers, types, sizes and positions in cracks do not differ between new Comp A-3 and Fleet stores old Comp A-3 after temperature cycling and no cracks exceed 1/32 inch.

- In 5"/54 projectiles, numbers of cracks roughly double when new Comp A-3 is the explosive load but these cracks do not differ in location, size or type from other Comp A-3 loads.

- In both 5"/38 and 5"/54 projectiles there is no difference in the growth of cracks between new Comp A-3 and the other Comp A-3 loads and growth generally does not exceed 1/64 inch.

- Cracks in the lower third of all projectiles are few in number, narrow in width (less than 1/64 inch) and are not distinguishable among any of the types of Comp A-3 evaluated in both 5"/38 and 5"/54 projectiles.

Conclusions cited in the Ammunition Special Study Group Report[1] were reviewed. Unfortunately, of the 90 Fleet stock rounds chosen for

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[1] *Op cit.*

firing because of the severity of their defects, no quantitative, numerical distinction was made between those with base gaps and those with major crack defects. However, it is clear from the report that:

> "...(no prematures) {were} obtained by firing several rounds with cracks and related defects - not at the base - but with gaps of about 1/8". These show that defects of this type (as are being produced by temperature cycling) probably are not as important as the defects {base gaps} considered here."[1]

At least two of the cracks were reported to be "...within 1-1/2" of the end of the BDF hole plug."[1*] Of 12 rounds fired from McAlester Lot BE-52-McA-69 there were a "Large number of wall to wall cracks - 4-7" from base."[1**] Eight rounds from Lot BE-McA-69 had cracks at least 1/8 inch wide.[1***] The cracks in the proof pressure fired rounds were larger in width and length and were closer to the projectile base area than any of those encountered in this study. None of the 90 defective rounds malfunctioned on proof pressure firing.

Based upon the results obtained from both studies it was concluded that post-1973 manufactured Comp A-3 could be loaded safely into all 5" projectiles with high confidence that performance would not be degraded if quality were maintained within the criteria established by NEDED and approved by the Naval Sea Systems Command in May 1975.[3] Thus, the Ammunition Special Study Group had concluded that cracks do not become a safety consideration until 1/8-inch cracks exist in the bottom 2 inches of the explosive fill. The recommended and approved specification just referenced does not allow such a condition to even be approached.

III. PRESSING EFFECT STUDIES

A. Approach

The pressing effect studies were designed to: quantify the pressure-density profiles in 5" projectiles; establish the maximum/minimum pressure limits that, statistically, would assure production of quality rounds; and demonstrate that substantial safety margins existed around the chosen operating pressures.

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[1] *Op cit.* p 2-20, par 2.6.4.11 (U)
 *p 4-44, par 4.3.7.1 (U)
 **p 4.3.5, par 4.3.7 (U)
 ***p 4.3.6, Table 4-11 (U)

[3] WS 13574A, *Projectile, 5 Inch 54 Caliber, Mk 64 Mod 0, Composition A-3 Explosive Loaded,* 23 May 1975

Pressure-density profiles were determined by press loading a minimum of four projectiles each at pressures ranging from 2,000 to 15,000 psi. Overall densities and minimum core densities were measured for each projectile set. The objective was to demonstrate that the average overall and average minimum core densities would lay well above the specified minimums provided that projectiles are loaded at the appropriate pressures. Comparative densities of 1/2-inch by 1/2-inch cylinders of Comp A-3 pressed over a 2,000 to 20,000 psi range were also measured. This comparative approach made it possible, by extrapolation, to determine the upper pressure limits beyond which no improvements in projectile densities are obtainable without the necessity or added hazard of operating the large projectile presses themselves over the high pressure (15,000 to 20,000 psi) range.

Pressure-flow characteristics were examined by: dyeing each Comp A-3 increment a different color; changing ram configurations; and sectioning the loaded projectiles. These studies were designed to yield possible explanations for: the formation of low density areas (particularly in the bottom half of the No. 2 core); increment separations; reassertion problems, etc.

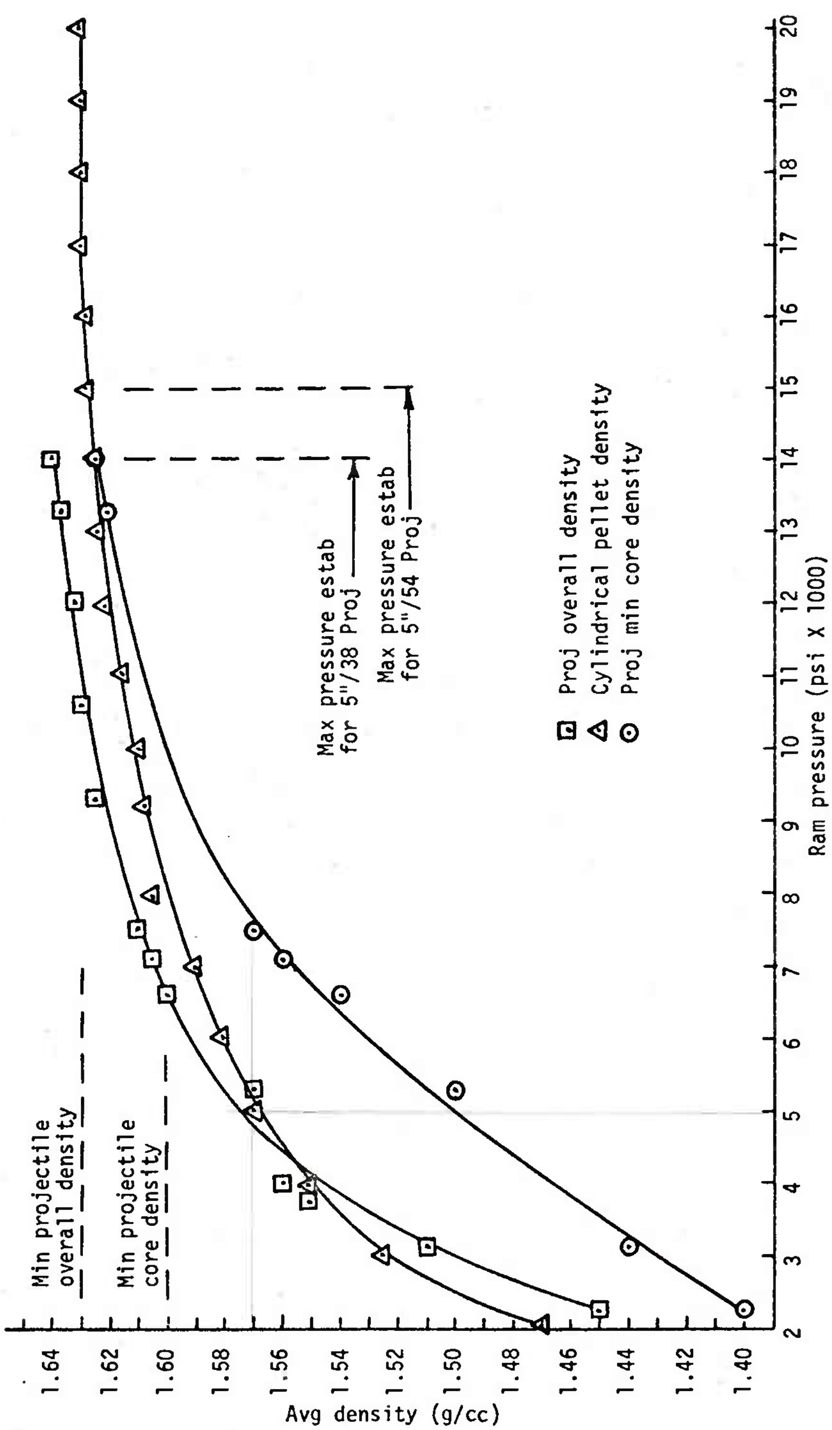
B. Pressure-Density Profile Studies

Only 5"/38 projectiles and 1/2-inch by 1/2-inch pellets were studied over the entire pressure range. Pressure-density relationships for 5"/54 projectiles were determined only in 13,500 to 15,000 psi range since data has established in the past that quality density rounds cannot be obtained at pressures below 13,000 psi. Projectile pressing conditions were:

- 0.81 g/cc Comp A-3 density.
- 68° to 80°F temperature range.
- 6-increment projectile load.
- 6-second dwell time.
- 85 inches per minute ram speed.

1. Results

All of the pressure-density data are summarized in Figure 5. Each point plotted represents the average of from 4 to 15 samples. Projectile overall densities and pellet densities follow fairly parallel increases with pressure, with both leveling off at the 14,000 to 15,000 psi range. Projectile minimum core densities reach pellet density values at the 14,000 to 15,000 psi range. Pellet data shows that no density advantage is attained from pressures



5"/38 PROJECTILE PRESSING EFFECT STUDY
PRESSURE-DENSITY PROFILE
FIGURE 5

above 15,000 psi. Projectile overall and minimum core densities in the 14,000 to 15,000 psi range consistently exceed the minimum specified.

The 5"/54 projectile results obtained over the 13,500 to 15,000 psi loading range were comparable to the 5"/38 data but are not included in Figure 5. Thus, for over 100 5"/54 projectiles examined, the average overall densities exceeded 1.640 g/cc at 15,000 psi and the average minimum core densities exceeded 1.620 g/cc.

2. Conclusions

- Optimum pressing pressures of 14,000 psi for 5"/38 and 15,000 psi for 5"/54 projectiles have been verified.

- Statistical analyses of overall projectile and minimum core densities obtained at these pressures gave confidence and reliability assurance levels of over 99.9 percent that density specifications would be met or exceeded.

- Within the temperature (68° to 80°F) and pressure (14,000 psi) limits established, a safety factor of at least 10°F and 1,000 psi exists before explosive column breakdown is realized in 5"/38 projectiles.

C. Pressure-Flow Studies

The main objective of those studies involving dyed explosive increments and varying ram configurations was to identify and, if possible, eliminate cracking. The studies were run concurrently with the temperature effect work described in Section II. It quickly was apparent, from the temperature effect studies, that temperature variations had far greater influence on crack formation than any other single variable or group of variables. Nonetheless, interesting data were generated from the pressure-flow studies.

1. Dyed explosive increment results

In the late 1960's and early 1970's, 5" projectiles were press loaded with dyed explosive to develop optimum explosive increment numbers and sizes (by weight). Figure 6 is a photograph of a sectioned 5"/38 projectile from that era. Figure 7 is a sketch clarifying the loading pattern shown in the photograph. For many years it was presumed that this loading pattern, distinguished by its sharply defined interfaces and uniformly spaced increments, was an accurate and authentic representation of the Comp A-3 explosive flow in 5" projectiles. However, the differences found in core densities taken from various positions in projectiles loaded during both the previously

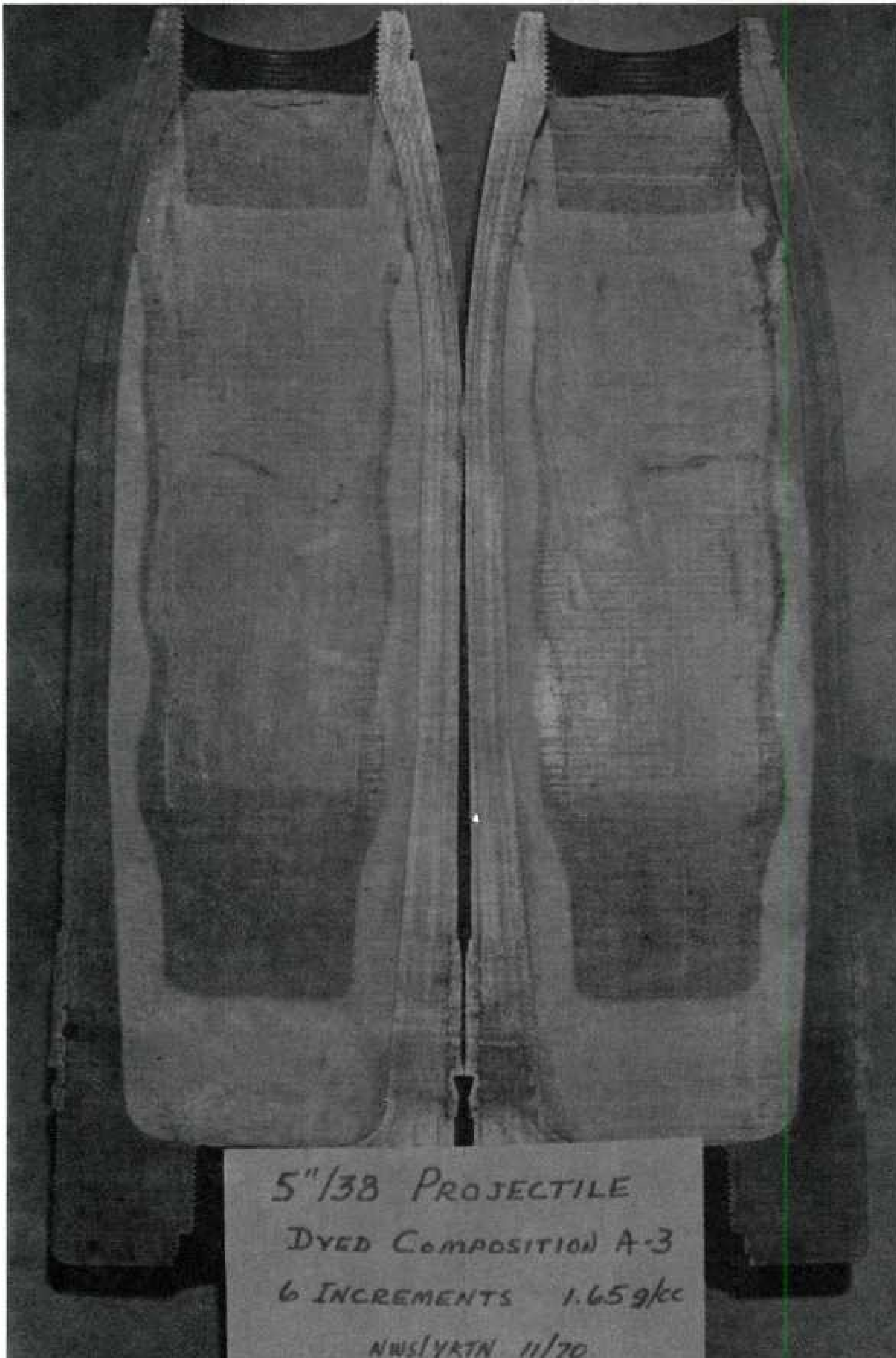
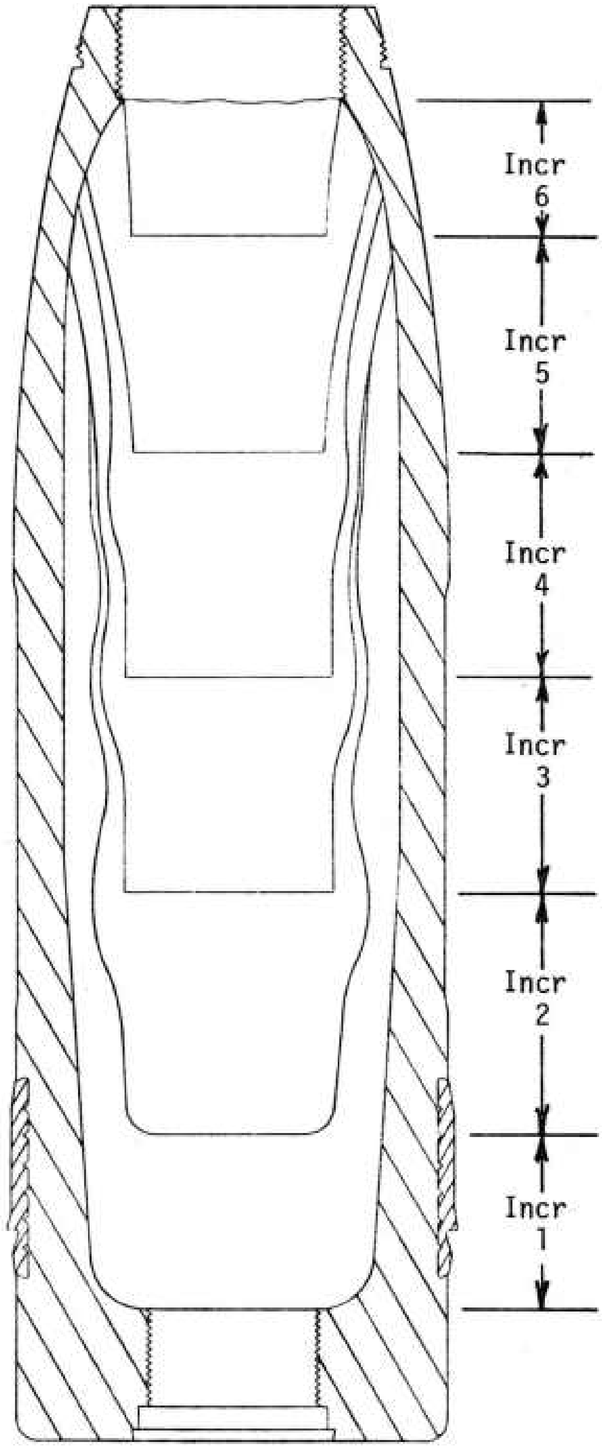

5"/38 PROJECTILE
DYED COMPOSITION A-3
6 INCREMENTS 1.65 g/cc
NWS/YKTN 11/70

FIGURE 6



<u>Pressing conditions</u>

Ram pressure:	13,250 psi
Ram speed:	85"/min
Temperature:	68°F
Dwell time:	6 sec
No. of incr:	6

5"/38 PROJECTILE PRESSING EFFECT STUDY
INCREMENT POSITIONS

FIGURE 7

reported study[2] and in this study were not reconcilable with expectations. That is, it reasonably would be expected that equally spaced increments and constant press pressures would result in consistent core densities throughout the explosive charge. This has not been found to be the case in the current work, regardless of whether 6-, 7- or 8-increment loading plans were followed. Instead, the bottom of either the No. 2 or No. 3 core invariably always has been the region of lowest density in 5"/38 and 5"/54 projectiles, respectively.*

Another unexplained phenomena was the fact that when explosive cracks were detected in projectile radiographs, they were most often dish-shaped, as shown in Figures 2 and 3, rather than flat and linear as might be expected if they occurred at the increment demarcations shown in Figure 6. Finally, photographs of sectioned projectiles generated during the current study bore no resemblance to the increment configurations of Figure 6 even when full consideration had been given to the fact that minor changes had been made in the numbers and weights of the increments involved. Thus, Figures 8 and 9 are photographs of 5"/38 and 5"/54 sectioned projectiles from the current study. Table IV is a listing of the pounds of explosives used per increment for various 5" projectile loading plans. Columns 1, 2 and 3, Table IV, are the increment weights used when 0.81 g/cc bulk density Comp A-3 was loaded into the projectiles depicted in Figures 6, 8 and 9, respectively. Columns 4 and 5 represent increment plans developed during that part of the reported study[2] where seventh and eighth increment options were prescribed to cover a broader Comp A-3 bulk density range, i.e., 0.75 to 0.82 g/cc.

It is apparent immediately that the major differences between the explosive flow patterns of Figure 6 on one hand and Figures 8 and 9 on the other cannot be attributed to the relatively minor changes in increment weights. Considering solely the fact that 3.6 to 4.0 pounds of explosive represents almost one-half the 8.6-pound total projectile load, it is clear that Figure 6 cannot represent the loading plan shown in Column 1, Table IV. The same observation holds for the discrepancies that exist between subsequent increment sizes and their purported explosive weights. Indeed, it eventually was discovered that in the 1970 study, the technician was trying to establish exact interface locations. He had found that loose powder fell into the unfilled cavity from the projectile side walls when the ram was withdrawn after each increment pressing. The result was that clear-cut increment lines could not be readily distinguished. Therefore, the

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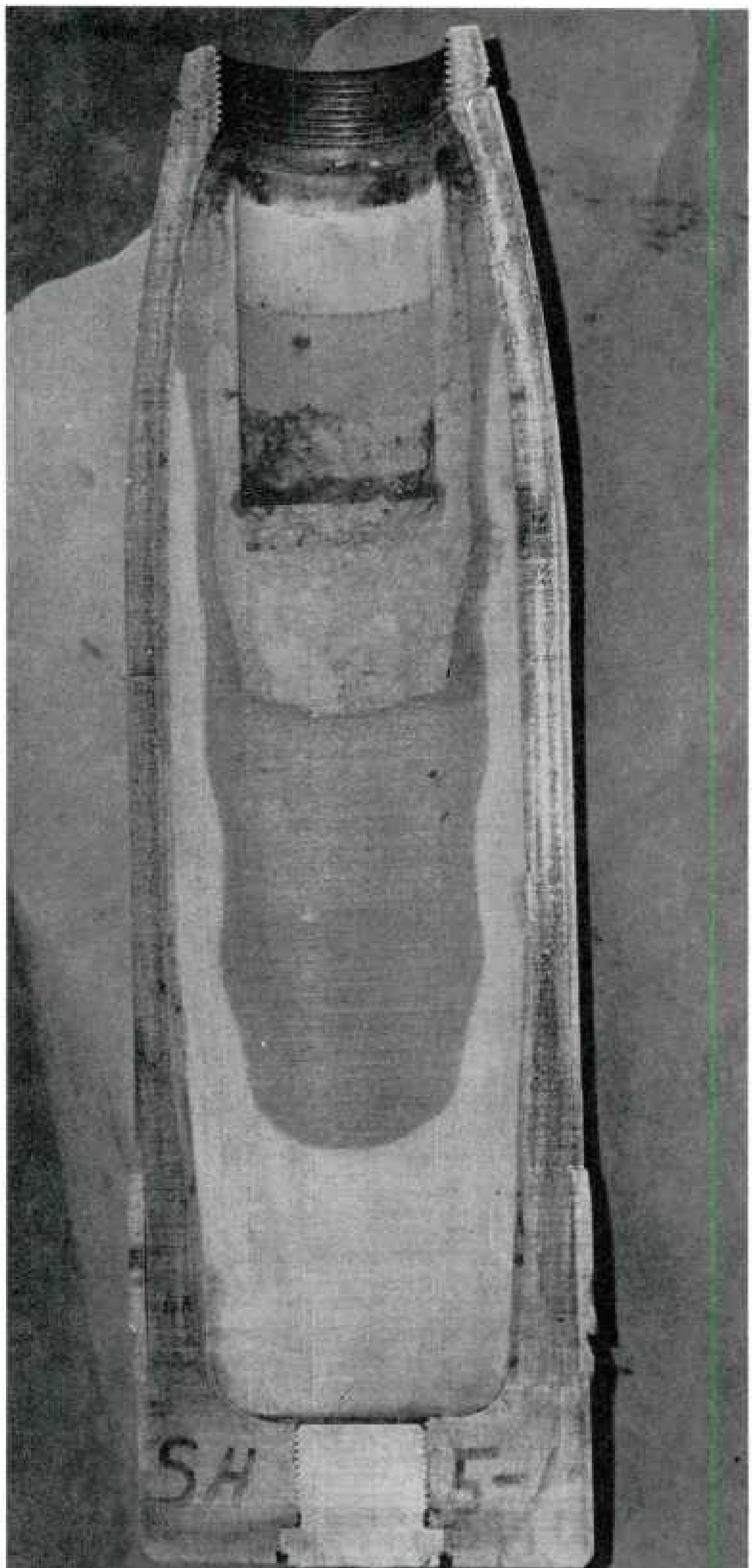
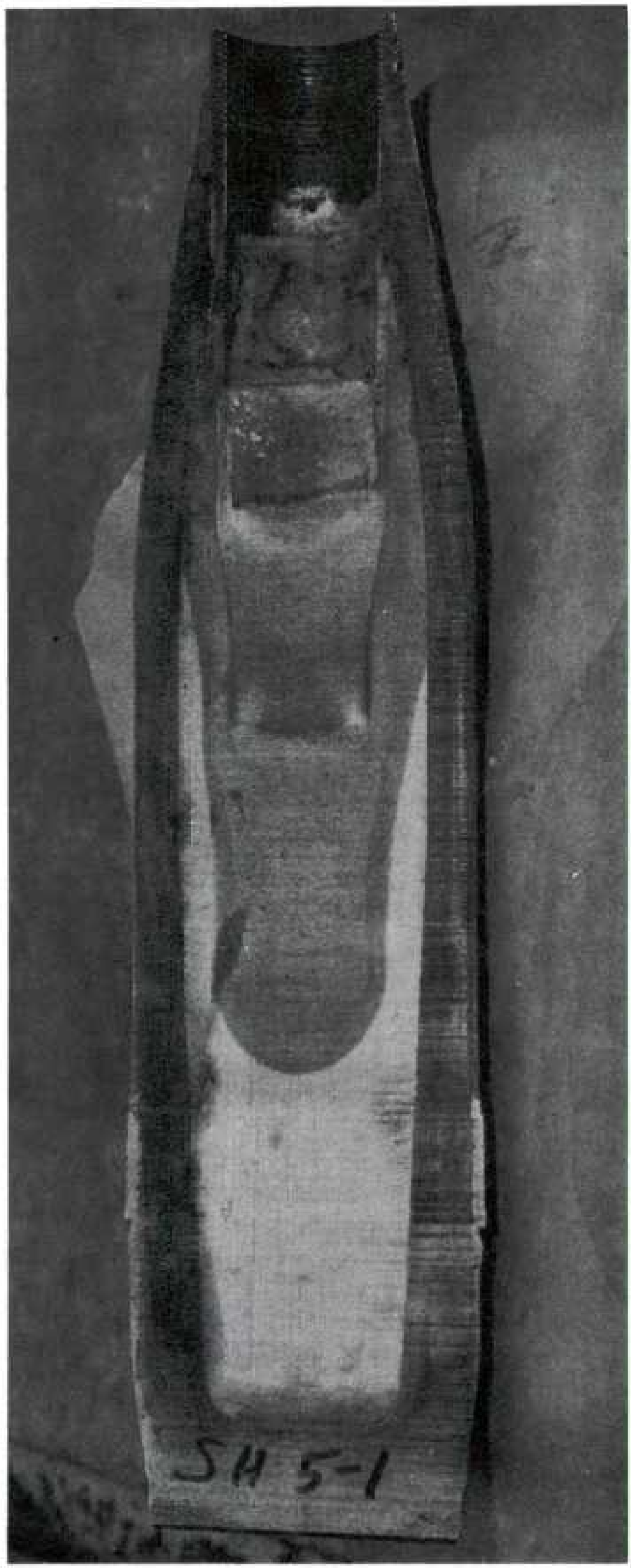
[2] *Op cit.*

*Density variations of this type are more striking in 5"/54 projectiles because explosive increments are longer. Here, not only is the bottom of the No. 2 core the region of lowest density but is invariably the region of greatest density variation (0.015 to 0.030 g/cc) between core top and bottom.



5"/38 PROJECTILE PRESSING EFFECT STUDY
EXPLOSIVE FLOW PATTERN
FIGURE 8



5"/54 PROJECTILE PRESSING EFFECT STUDY
EXPLOSIVE FLOW PATTERN
FIGURE 9

TABLE IV

5"/38 AND 5"/54 PROJECTILE PRESSING EFFECT STUDY
INCREMENT LOADING PLANS

Incr No.	Composition A-3 (lbs)				
	Col 1[a] (5"/38)	Col 2[b] (5"/38)	Col 3[c] (5"/54)	Col 4[d] (5"/38)	Col 5[e] (5"/54)
1	3.60	4.00	3.60	4.00	3.60
2	1.60	1.30	1.60	0.90	0.90
3	1.30	1.20	1.30	1.10	1.20
4	1.05	0.90	1.00	1.00	1.10
5	0.70	0.60	0.65	0.60	0.80
6	0.45*	0.40	0.45	0.45	0.50
7	-	0.20*	-	0.35*	0.30*
8	-	-	-	0.25*	0.20*

[a] 1970 loadings (Figures 6 and 7).

[b] Current study, loads similar to 1970 loadings (Figures 8 and 10).

[c] Current study, loads similar to 1970 loadings (Figures 9 and 11).

[d] Current study, current standard loads (Figure 12).

[e] Current study, current standard loads (Figure 13).

*Final increment(s) added or varied as required to compensate for varying bulk densities and/or varying projectile cavity volumes.

technician had carefully vacuumed out all such loose powder before adding and pressing subsequent increments. This operation was not entered on the data sheet or otherwise reported. Once this procedural change was uncovered, it became clear that Figures 8 and 9 accurately represent the Comp A-3 fallback and pressure flow characteristics in 5' projectiles. In turn, explosive core density data became more readily interpretable.

Figures 10 and 11 are sketches of the photographs in Figures 8 and 9 superimposed upon the increment loading plans that had been developed for 5"/38 and 5"/54 projectiles where 0.81 g/cc bulk density Comp A-3 was the explosive load. The overlap of explosive from each weigh-in into the "true increment positions"* is the most striking feature of these figures. This overlap does not occur in Figure 6.

Figures 12 and 13 are sketches of 5"/38 and 5"/54 projectiles that show the true increment and core locations in rounds loaded under standard conditions for any bulk density range using the increment weights listed in Columns 4 and 5 of Table IV. The data posted on each sketch is a composite average of the true increment positions and of the core densities from 50 projectiles of each type. The Comp A-3 flow patterns are not shown on these sketches but are similar in configuration to the 6- and 7-increment patterns depicted in Figures 10 and 11.

2. Conclusions

Several major conclusions can be drawn from Figures 12 and 13.

- The amount of explosive distributed in each increment is different, being proportionate to: the quantity of explosive poured into the projectile in the first place (Table IV); the amount of fallback; and the internal geometry of the cavity.

- 5"/54 projectiles have the longest increments, are more difficult to press and, consequently, exhibit the greater density variations.

- Except in those areas where internal geometry and/or flow-by have minor influence, it is generally true that the spread in core densities (or density gradients) are greatest and in direct proportion to increment lengths. In short, the increment size versus core density results do follow expectations.

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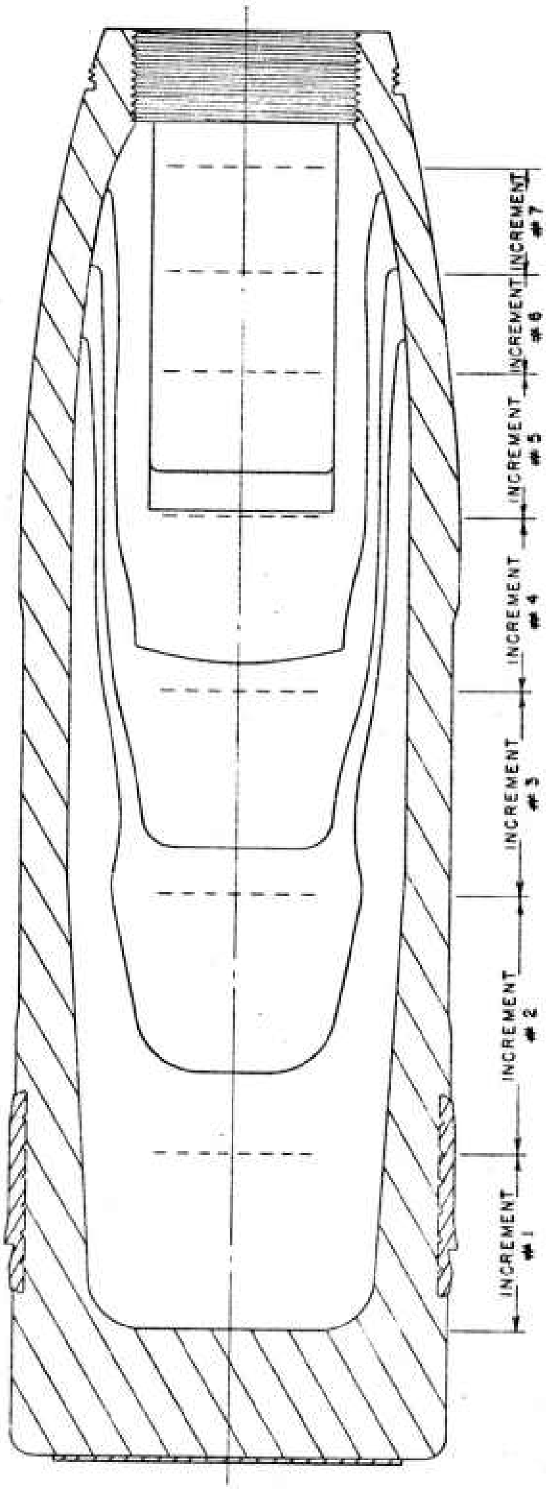
*"True increment positions" are measured with a calibrated rod inserted into the projectile until it passes through fallback material and bottoms out upon each increment load after it is pressed. Cores are then taken between these measured increment faces.

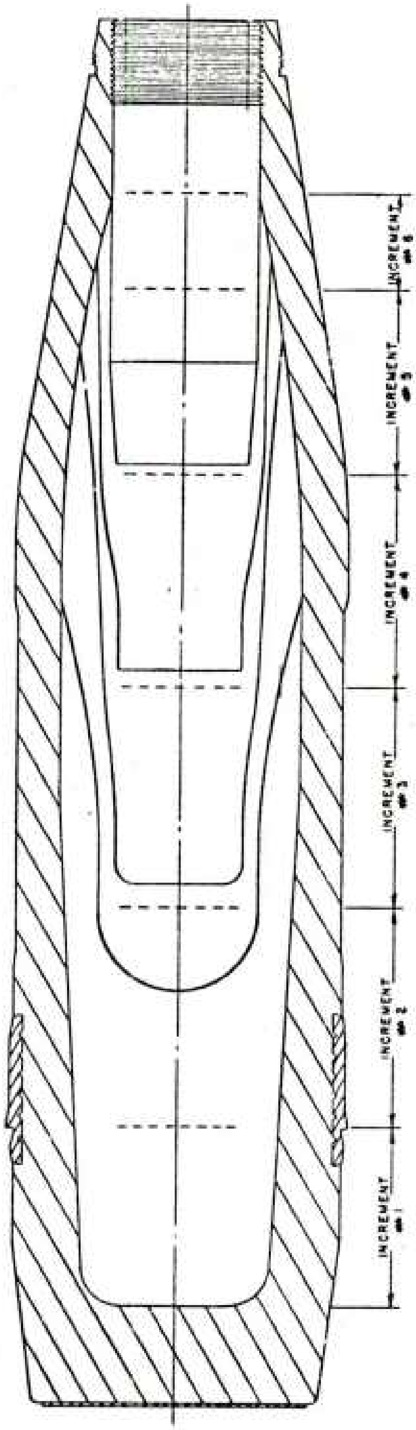


<u>Pressing conditions</u>

Ram pressure:	14,000 psi
Ram speed:	85"/min
Temperature:	68°F
Dwell time:	6 sec
No. of incr:	7

5"/38 PROJECTILE PRESSING EFFECT STUDY
INCREMENT POSITIONS AND EXPLOSIVE FLOW PATTERN

FIGURE 10

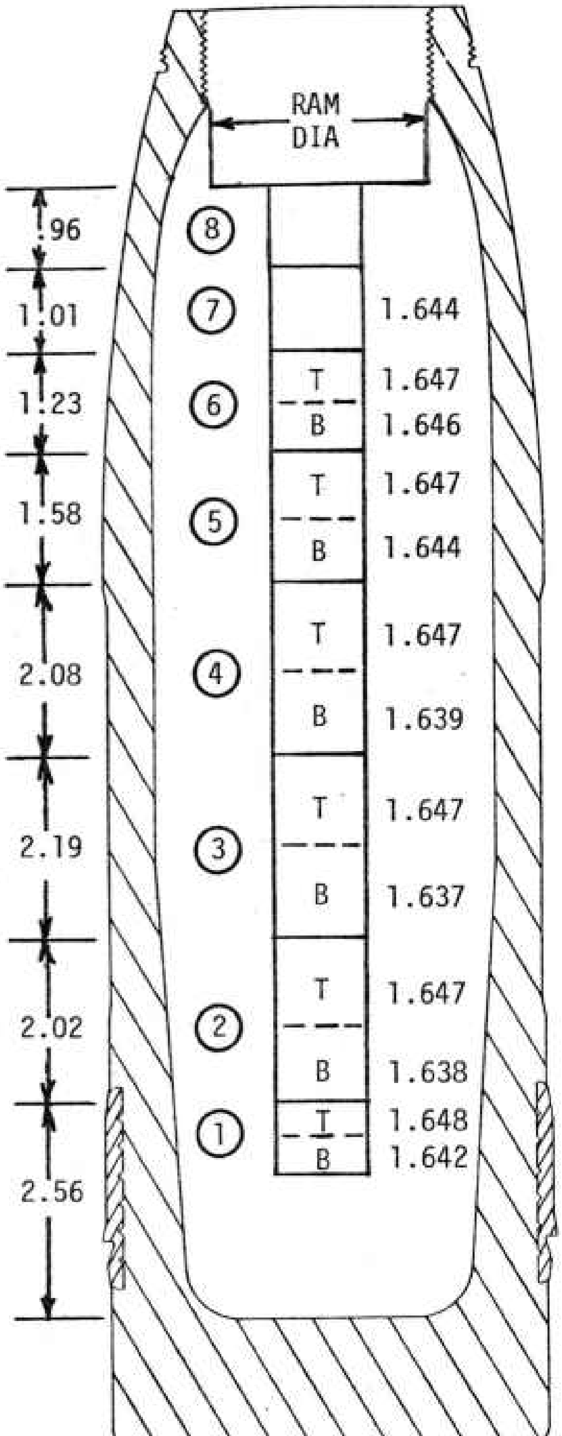


Pressing conditions

Ram pressure:	15,000 psi
Ram speed:	85"/min
Temperature:	68°F
Dwell time:	6 sec
No. of incr:	6

5"/54 PROJECTILE PRESSING EFFECT STUDY
INCREMENT POSITIONS AND EXPLOSIVE FLOW PATTERN

FIGURE 11



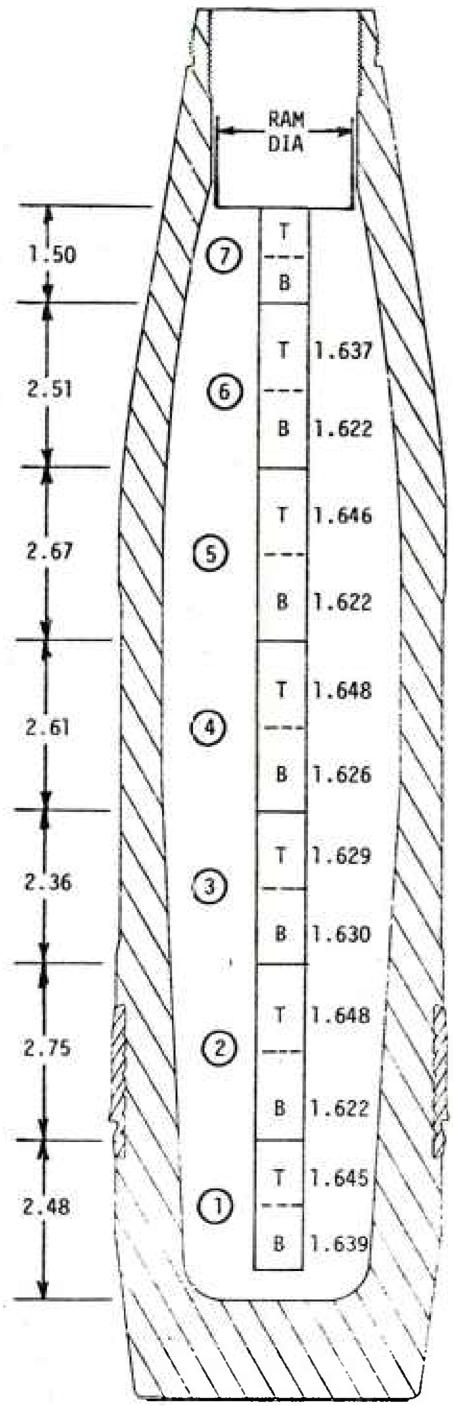
1 Increment No.

<u>Pressing conditions</u>

Overall density:	1.648 g/cc (avg)
Bulk density:	0.79-0.80 g/cc
Ram:	Standard
Ram pressure:	14,000 psi
Ram speed:	85"/min
Temperature:	80°F
Dwell time:	6 sec
No. of incr:	8

5"/38 PROJECTILE PRESSING EFFECT STUDY
CORE DENSITY VS INCREMENT SIZE

FIGURE 12



1 Increment No.

Pressing conditions

Overall density:	1.643 g/cc (avg)
Bulk density:	0.79-0.80 g/cc
Ram:	Standard
Ram pressure:	15,000 psi
Ram speed:	85"/min
Temperature:	80°F
Dwell time:	6 sec
No. of incr:	7

5"/54 PROJECTILE PRESSING EFFECT STUDY
CORE DENSITY VS INCREMENT SIZE

FIGURE 13

Figure 14 illustrates the above conclusions taken from Figure 13 data for 5"/54 projectiles. Plotted on the ordinates are density spreads (left scale) and minimum core density (right scale) versus increment size for 50 projectiles. The generally linear relationships are as expected. Deviations from linearity as in the case of the No. 6 core are explained by the fact that the sidewalls have filled with extruded Comp A-3 by the time the sixth increment is pressed. This formed cylindrical cavity results in an increment of less density spread even though the increment size (2.5 inches) is relatively large. Conversely, the No. 3 core spread is relatively high despite the smaller increment size because the projectile cavity is approaching maximum diameter and has not completely filled in with extruded Comp A-3.

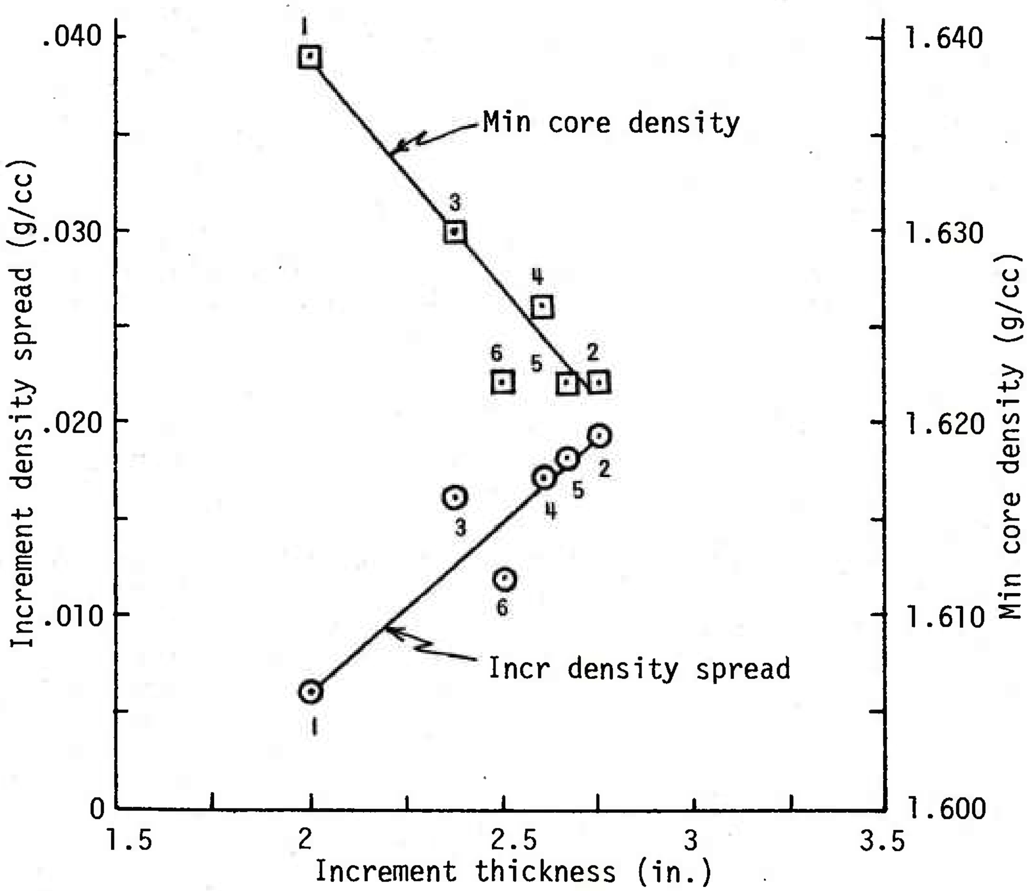
A comparison of the representative cracking patterns illustrated in Figures 2 and 3 and the stress-flow lines indicated on Figures 10 and 11 lead to the inevitable conclusion that cracks are most likely to form at the stress contours where not only is the shear rate high but where the cohesive waxes may actually be extruded from between the highly sheared RDX crystals leaving interfaces of low tensile strength.

3. Variable ram configuration results

It was postulated earlier that such undesirable characteristics as changing core densities, increment separations, reassertion and cracks all might be related to ram force configurations. This was not an arbitrary supposition since it has long been the practice in the multi-increment pressing of propellants and pyrotechnics to use dimpled, tapered, step-faced and other ram configurations to alleviate one or more of the following conditions: air entrapment; ram sticking; non-bonding of increments; and cracks.

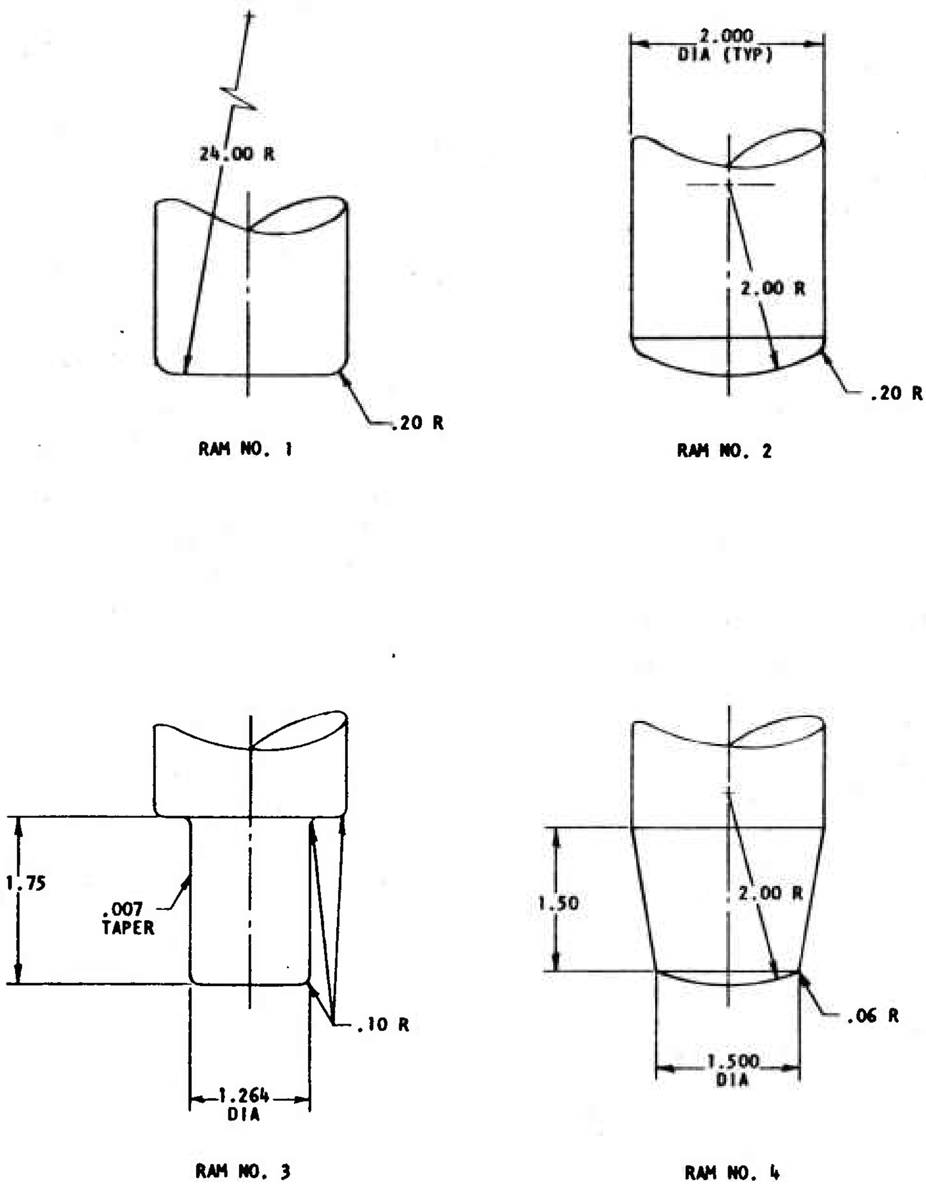
For these reasons, a variety of ram configurations were evaluated as part of this study and are shown in Figure 15. In all, 50 each 5"/54 projectiles were pressed with each configuration.

Although none of the loads developed more cracks than the "standard" ram configuration, other problems arose. Thus, the ram shapes that departed most from the standard right cylinder configuration exhibited the lowest density areas (down to 1.47 g/cc). For example, it originally was theorized that the stepped ram would cause the increment being pressed to interlock with the previous one, would "chock" the explosive and thereby eliminate cracking. However, both radiographs and core samples showed densities in the interface area to be considerably below standard values - a sure indication that no interlocking action occurs. Typical results obtained using the stepped ram as compared to standard ram for 5"/54 projectiles are listed in Table V.



5"/54 PROJECTILE PRESSING EFFECT STUDY
CORE DENSITY VARIATIONS

FIGURE 14



5"/54 PROJECTILE PRESSING EFFECT STUDY
RAM CONFIGURATIONS

FIGURE 15

TABLE V

5"/54 PROJECTILE PRESSING EFFECT STUDY
TYPICAL CORE SAMPLE DENSITY

		Core density (g/cc)					
Core No.		1	2	3	4	5	6
Top sample	a	-	1.652	1.653	1.653	1.653	1.653
	b	-	1.655	1.652	1.638	1.632	1.595
Bottom sample	a	1.650	1.636	1.643	1.639	1.638	1.649
	b	1.647	1.653	1.626	1.585	1.473	1.488

[a]Ram: Standard
Bulk density: 0.81 g/cc
Temperature: 68°F

[b]Ram: Stepped
Bulk density: 0.82 g/cc
Temperature: 78°F

Pressing constants

Ram pressure: 15,000 psi
Ram speed: 85"/min
Dwell time: 6 sec
No. of incr: 8

4. Conclusions and recommendations

In essence, these experiments demonstrated that any radical changes to the standard right cylinder ram configuration produced poor quality loads and it is recommended that no further investigations of this type be attempted again. More recent studies have shown that the reassertion problem is not nearly as major as originally thought when proper operating controls are exercised.

IV. REFERENCES

1 NAVORD Rept 10009, *Report of the Ammunition Special Study Group (U)*, 1 Aug 1970 CONFIDENTIAL

2 McGann, E. Yancey, Rothstein, Lewis R., NWSY TR 76-1, *A Safety, Quality and Cost Effectiveness Study of Composition A-3 Press Loading Parameters*, Mar 1976

3 WS 13574A, *Projectile, 5 Inch 54 Caliber, Mk 64 Mod 0, Composition A-3 Explosive Loaded*, 23 May 1975

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